



SETI INSTITUTE

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**Final Technical Report to
NASA Ames Research Center
For Cooperative Agreement NCC 2-1038 Entitled:**

"Studies of Transient Meteor Activity"

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Period of Performance: February 1, 1998 to November 30, 2001

CAST

PROPOSAL SUMMARY

Meteoroids bombard Earth's atmosphere daily, but occasionally meteor rates increase to unusual high levels when Earth crosses the relatively fresh ejecta of comets. These transient events in meteor activity provide clues about the whereabouts of Earth-threatening long-period comets, the mechanisms of large-grain dust ejection from comets, and the particle composition and size distribution of the cometary ejecta. Observations of these transient events provide important insight in natural processes that determine the large grain dust environment of comets, in natural phenomena that were prevalent during the time of the origin of life, and in processes that determine the hazard of civilizations to large impacts and of man-made satellites to the periodic blizzard of small meteoroids.

In this proposal, three tasks form a coherent program aimed at elucidating various aspects of meteor outbursts, with special reference to planetary astronomy and astrobiology.

Task 1. A ground-based effort to observe periods of transient meteor activity. This includes:

- a) stereoscopic imaging of meteors during transient meteor events for measurements of particle size distribution, meteoroid orbital dispersions and fluxes; and*
- b) technical support for Global-MS-Net, a network of amateur-operated automatic counting stations for meteor reflections from commercial VHF radio and TV broadcasting stations, keeping a 24h vigil on the level of meteor activity for the detection of new meteor streams.*

Task 2. Ground-based and satellite born spectroscopic observations of meteors and meteor trains during transient meteor events for measurements of elemental composition, the presence of organic matter in the meteoroids, and products generated by the interaction of the meteoroid with the atmosphere.

Task 3. An airborne effort to explore the '00 Leonid meteor outbursts, which are anticipated to be the most significant of transient meteor activity events in the remainder of the agreement period. This includes technical support for a multi-instrument aircraft campaign, Leonid MAC.

PROGRESS REPORT

Task 1 is concerned with the characterization of periods of transient meteor activity by measuring the orbits of individual particles, determine the dispersion of the orbital elements in relation to the orbit of the comet, measure meteor brightness distributions and meteor shower activity profiles that define the dispersion in the orbit node in the path of the Earth. This task aims to provide ground truth for models of meteoroid stream formation, such as ejection velocities, particle size distributions, and total amount of ejected dust. The task also studies the encounter conditions of Earth and meteoroid streams searching for clues of what physical mechanisms determine the occurrence of transient meteor activity on Earth.

Progress and results

Ground-based efforts in year 03 focussed on the Leonid shower of November 2000, with a practice session during the August Perseids. A ground-based Leonid campaign was organized at sites in Florida (ISTEF, Cape Canaveral) and Mount Lemmon Observatory, Arizona, to cover the encounters with the 1932 and 1866 dust trails. At the same time, observing campaigns in Spain and the Netherlands were executed by the Dutch Meteor Society to observe the 1733 dust trail encounter. The outbursts occurred much as predicted and established the multi-trail model as a valid premise. The same tools were used to forecast an outburst of the December Ursid shower, which was observed from California and detected much as predicted.

Leonids

The data reduction and analysis effort tackled the formation and evolution of cometary dust trails, specifically that of comet 55P/Tempel-Tuttle, as well as the grain composition and morphology that determine breakup, aging, and the level of interaction with solar radiation and wind. Based on the Leonid shower observations, we derived fundamental properties of comet mass loss and meteoroid morphologies from the observed dust dispersion during the 1999 and 2000 Leonid outbursts. We find a nominal meteoroid density of $0.97 \pm 0.13 \text{ g/cm}^3$. A much smaller $\sim 0.2 \text{ g/cm}^3$ was expected, because the Leonid meteoroids are seen to fall apart more easily than normal annual shower meteoroids. This could mean that the organic glue that holds the grains together changes in nature with increased exposure in the planetary medium.

P. Jenniskens, 2001. Model of a 1-revolution dust trail from Leonid outburst observations. WGN, the Journal of IMO 29: 5, 165-175.

P. Jenniskens, 2001. Forecast for the remainder of the Leonid storm season. ESA SP-495, Proceedings of the Meteoroids 2001 Conference, Swedish Institute of Space Physics, Kiruna, Sweden, 6-10 August 2001, p. 83-90.

These papers also make predictions for the level of activity and the timing of the 2001 and 2002 Leonid storms, with critical implications for the projected November 2001 Leonid MAC mission. In particular, the 1767 dust trail encounter was found more favorable than thought before, enabling a local effort in the continental USA, rather than an international campaign.

Some headway was made with the analysis of data from the 1999 storm encounter. Our research focussed on the absolute calibration of meteor fluxes during the 1999 Leonid storm in order to better address the satellite impact hazard.

D. Holman, P. Jenniskens, 2001. *Leonid Storm Flux from Efficient Visual Scanning of 1999 Leonid Storm Video Tapes*. WGN, the Journal of IMO 29, 77-84.

Long-period comets

Research on long-period comet dust trails were pursued further by studying the dust trail dynamics using the new methods of predicting the Leonid showers. A new approach was developed for outbursts from such long period comet dust trails. An application to all such known showers with predictions for future returns was submitted for publication. The special case of long-period comet C/2000 WM1 was studied in detail because a shower was predicted by others. Based on our calculations, we could not confirm this prediction, and no shower was observed.

P. Jenniskens, E. Lyytinen, 2001. *No outburst of comet C/2000 WM1 (Linear)*, WGN, the Journal of IMO 29:1, 35-37.

E. Lyytinen, P. Jenniskens, 2002. *Meteor outbursts from Long-Period comet dust trails*. ICARUS (submitted).

Ursids

A very successful prediction was made of a possible outburst of Ursids on December 22, 2000. The shower was predicted to be caused by dust released in 1392 and 1405. This forecast was widely announced, including via an Ames press release, and was observed from a ground location in California. The event was detected much as predicted. A full report was submitted to ICARUS.

P. Jenniskens, E. Lyytinen, 2000. *Possible Ursid Outburst on December 22, 2000*. WGN, the Journal of the IMO 28:6, 221-226 (<http://leonid.arc.nasa.gov/leonidnews28.html>)

P. Jenniskens, 2000. *Ursid Meteors 2000*. IAUC 7544 (prediction) and 7548 (confirmation), D.W.E. Green (eds.), IAU Minor Planet Center, December 18, 2000.

P. Jenniskens, E. Lyytinen, 2001. *Ursid outburst confirmed*. WGN, the Journal of the IMO 29:1, 41-45.

P. Jenniskens, E. Lyytinen, M.C. de Lignie, C. Johannink, R. Schievink, M. Langbroek, M. Koop, P. Gural, M.A. Wilson, I. Yrjola, K. Suzuki, H. Ogawa, P. de Groote, 2001. *Dust trails of 8P/Tuttle and the unusual outbursts of the Ursid shower*. ICARUS (submitted).

Task 2 is concerned with the spectroscopic characterization of the meteoroids themselves and their chemical and physical products by interaction with the Earth's atmosphere. Of special interest is the organic component of cometary meteoroids and the organic components generated by the meteoric process, which may have played a role in the origin of life. The thrust of this task is the construction of an astrobiology instrument for the participation in the November '98 Leonid multi-instrument aircraft campaign. Periods of transient meteor activity provide the necessary enhanced fluxes that are needed to use observational techniques that would normally suffer from low detection rates. Of interest too, are potential differences between meteoroids in these transient events as opposed to meteoroids that cause the sporadic background and the annual meteor showers.

Progress and results

An earlier problem in operating the CCD spectrograph was identified as due to voltage spikes when one of the cables was accidentally disconnected during operation. No further difficulties were encountered with this instrument and it was successfully deployed from the ground during the Perseid, Geminid and Ursid campaigns and during the 2000 Leonid campaign. New Perseid and Geminid spectra were added to the database that now include a few high-resolution spectra from meteors with lower entry velocity than those of the Leonids.

The fibre-optic coupled slit spectrograph was successfully deployed during the Perseid shower when one persistent train was observed. However, no signal was recorded. The subsequent work to increase the sensitivity of this instrument focussed on implementing Peltier cooling elements and new optical fibers.

New insight into the chemiluminescence mechanism and the physical conditions in the path of bright fireballs from optical spectroscopy and modeling of persistent trains was published, that further studied the physical conditions in the meteor path after matter has been deposited.

C. A. Kruschwitz, M.C. Kelley, C.S. Gardner, G. Swenson, A.Z. Liu, X. Chu, J.D. Drummond, B.W. Grime, W.T. Armstrong, J.M.C. Plane, and P. Jenniskens, 2001. *Observations of persistent Leonid meteor trails II: Photometry and numerical modeling. Journal Geophys. Res. (in press)*

New insight was gained as well into mid-Infrared emissions from persistent trains, the deposition of solid debris particles and the survival of organic matter in that debris. This work is still ongoing. The work included the setup of data reduction procedures at NASA Ames for MIRIS instrument data (IDL). Reduction of first fragment of video-rate data was completed. The framework for a radiative transfer model was put in place.

A review paper of the fate of organic matter in meteoroids during meteoric accretion was written as a contribution to the Meteoroids 2001 meeting in Kiruna, Sweden. The paper includes new insight into the interaction of air with the meteoroid ablation vapor cloud, pointing out that most meteoric vapor can leave the hot meteor head through a cool back door:

P. Jenniskens, 2001. *Meteors as a vehicle for the delivery of organic matter to the early Earth. ESA-SP 495, Proceedings of the Meteoroids 2001 Conference, Swedish Institute of Space Physics, Kiruna, Sweden, (Aug. 6-10, 2000) p. 247-254.*

Task 3 is concerned with the unusual Leonid meteor showers associated with the return of parent comet 55P/Tempel-Tuttle in February of 1998. During the Leonid showers of November 1998 and 1999, a Multi-Instrument Aircraft Campaign was organised to provide an observing platform for a wide range of instruments and an international team of researchers to study the anticipated meteor storm above clouds and from the best possible observing location. This task includes technical and logistic support for the Leonid multi-instrument aircraft campaign in preparation of and during both the November 12-22, 1998, and November 12-22, 1999, campaigns. This includes the organizational effort to bring planetary scientists, upper-atmosphere scientists and meteor physicists together for this concerted effort and a steering effort to achieve the scientific objectives.

Progress and results

A small Leonid campaign was organized during the 2000 November Leonid return in preparation of further missions in 2001 and 2002, for which proposals were prepared and submitted. The work included general coordination and facilitation of the research effort, travel support for participating scientists, deployment of instruments described in Task 2, and the organization of a Leonid MAC business meeting at the SETI Institute in May of 2001. First results from the Leonid campaign are presented in:

Jenniskens P., Gustafson B.Å.S., 2000. The rare 1932 dust trail encounter of 2000 November 17 as observed from aircraft. WGN, the Journal of IMO 28, 209-211.

The Leonid MAC website at <http://leonid.arc.nasa.gov> was maintained to reflect the ongoing effort and results of the research. Especially, a large effort was made to compile popular summaries of the research, which were published on the website in the days leading up to the November 2000 Leonid shower. Popular accounts were published, amongst others, in the New York Times and the San Jose Mercury News. A popular paper was written on request of David Blake for Scientific American and we contributed to a documentary project in HDTV by Ed Schilling, Code JIT, at NASA Ames Research Center:

D.F. Blake, P. Jenniskens, 2001. The Ice of Life. Scientific American. August issue (centerfold), p. 45-51.

A feasibility study for new Astrobiology related research in future Leonid MAC missions was performed. Sub-mm spectroscopic observations were considered a promising new direction. Sub-mm observations can detect organic molecules in the upper atmosphere that are possibly of extraterrestrial origin (HCN) or relevant for understanding efficiency of meteor induced chemistry (NO, O₃, CO). To further this research, we set up of collaboration with European Exobiology community in Bordeaux, France, and Bremen, Germany. Team performed a test observing run in August at Manua Kea, Hawaii.

Despois D., Ricaud P., Lautie N., Schneider N., Jacq T., Biver N., Lis D.C., Chamberline R.A., Phillips T.G., Miller M., Jenniskens P., 2000. Search for extraterrestrial origin of atmospheric trace molecules - radio submm observations during the Leonids. Earth, Moon and Planets 28-38, 129-140.

The work described under this cooperative agreement found its crown in November of 2000 with the publication and distribution of a 600-page book "Leonid Storm Research", with some 20 papers describing first results from the Leonid MAC mission based on FY00 data reduction effort. The publication was announced in an Ames press release.

P. Jenniskens, F. Rietmeijer, N. Brosch, M. Fonda (eds.), 2000. "Leonid Storm Research", special issue of Earth, Moon and Planets, Vol. 82-83, 600 pp.

To further the Leonid storm research, we contributed a special chapter to a new book on "Interplanetary Dust" and organized two special Astrobiology and Leonid storm research sessions at the Meteoroids 2001 meeting in Kiruna, Sweden (August 5-11, 2001)

P. Jenniskens, 2001. Discoveries from Observations and Modeling of the 1998/99 Leonids. In: Interplanetary Dust, Eberhard Gruen, Bo Å.S. Gustafson, Stan Dermott, and Hugo Fechtig eds., Springer Verlag, Heidelberg, New York, p. 233-252.

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